Proton Plan
MI RF Issues
Temple Review
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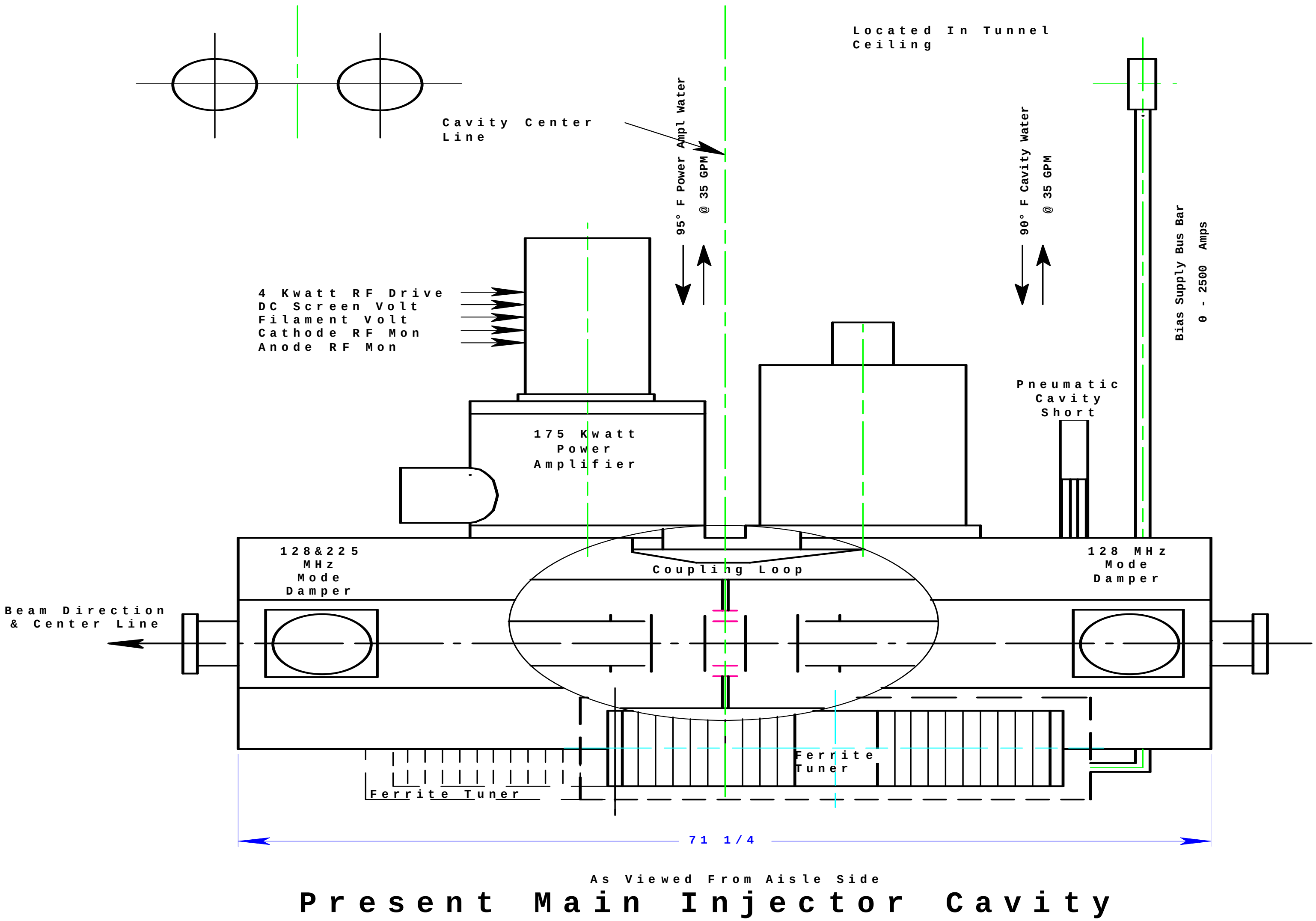
Introduction

- The current MI RF system consists of 18 stations (rf cavities, power amplifiers, power supplies and ancillary systems). The rf cavities are back to back folded resonator with a single accelerating gap fabricated out of copper. Each cavity is tuned over the operating frequency range 52.812-53.104 MHz by two biased ferrite tuners. The tuners and their coupling loop are water cooled as is the entire cavity.
- At present each cavity is driven by a single Eimac 4CW150000E power tetrode mounted directly on the cavity providing up to 175 KW (operationally). Each cavity is designed to operate at accelerating gap voltage of 240KV.
- At energies above transition the cavity impedance is measured to be around 500 KOhms(R/Q=104).
- We have a total of 3 spare cavities allowing the expansion to 20 stations (providing we can find the space).
- Each cavity has an extra port available for the installation of a second power tube.

Schematic of the MI rf Cavity



Current Capabilities

- The max amount of beam we can accelerate given the max RF voltage per station and the number of stations is a function of the acceleration rate.
- The MI magnet power supplies can support a max rate of 280 GeV/sec while currently we are running with a max acceleration rate of 205 GeV/sec.
- The MI cycle time is dominated by the 8 GeV front porch thus minimizing any gains from increased acceleration rate.

Main Injector Ramps

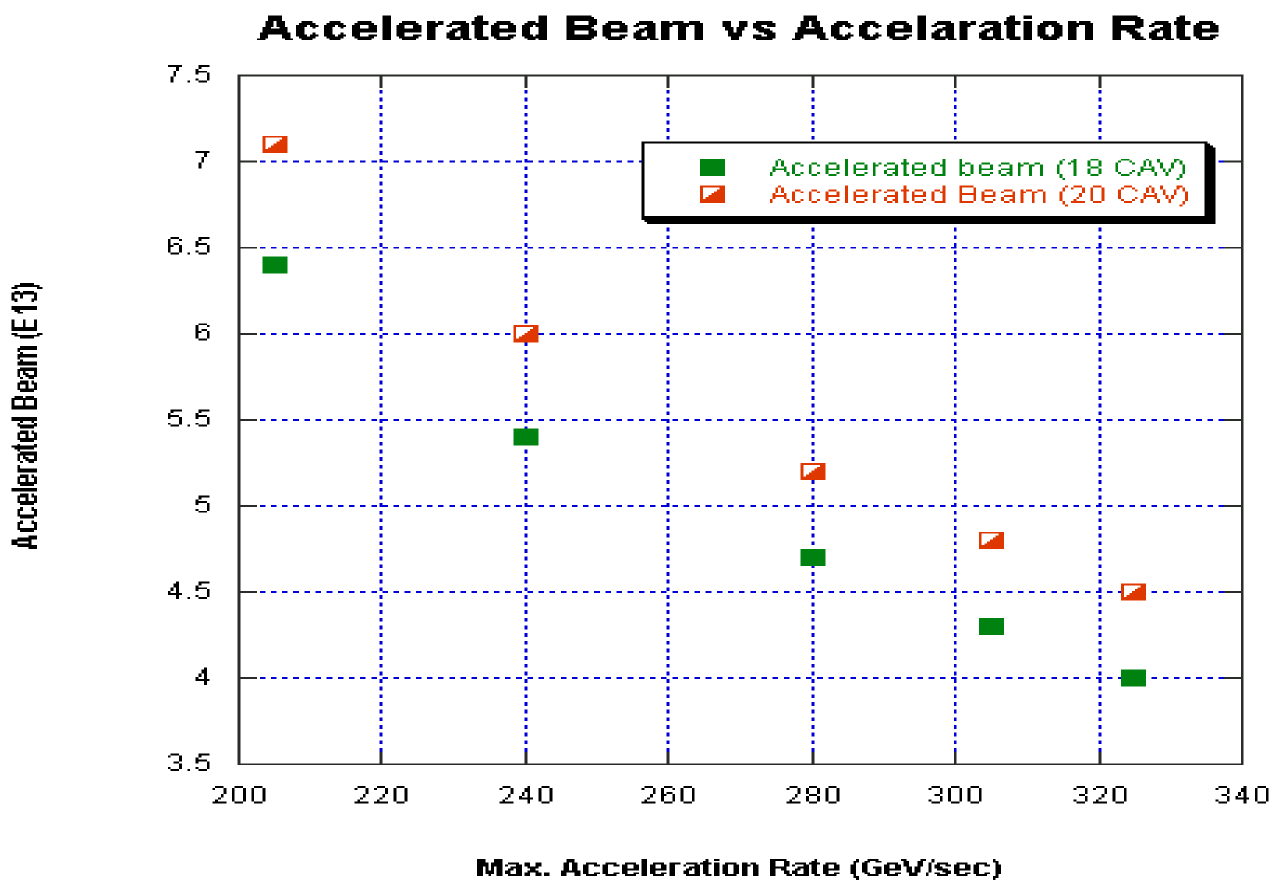
Present MI Ramp 1.87sec

Delta t	Time	Momentum	Pdot
0.50000	0.50000	8.884	0.00
0.02533	0.52533	8.96	6.00
0.04154	0.56687	9.5	20.00
0.11111	0.67798	22	205.00
0.30732	0.98530	85	205.00
0.15385	1.13915	115	185.00
0.05081	1.18996	119.7	0.00
0.07000	1.25996	119.7	0.00
0.09800	1.35796	105	-300.00
0.15517	1.51313	60	-280.00
0.19600	1.70913	11	-220.00
0.04182	1.75095	6.4	0.00
0.06198	1.81293	7.7945	45.00
0.04842	1.86135	8.884	0.00
0.00500	1.86635	8.884	0.00

Minimum Cycle Ramp 1.75sec

Delta t	Time	Momentum	Pdot
0.50000	0.50000	8.884	0.00
0.02533	0.52533	8.96	6.00
0.04154	0.56687	9.5	20.00
0.08333	0.65021	22	280.00
0.23774	0.88794	85	250.00
0.13636	1.02430	115	190.00
0.04947	1.07378	119.7	0.00
0.07000	1.14378	119.7	0.00
0.09639	1.24017	105	-305.00
0.15385	1.39402	60	-280.00
0.19600	1.59002	11	-220.00
0.04182	1.63184	6.4	0.00
0.06198	1.69381	7.7945	45.00
0.04842	1.74224	8.884	0.00
0.00500	1.74724	8.884	0.00

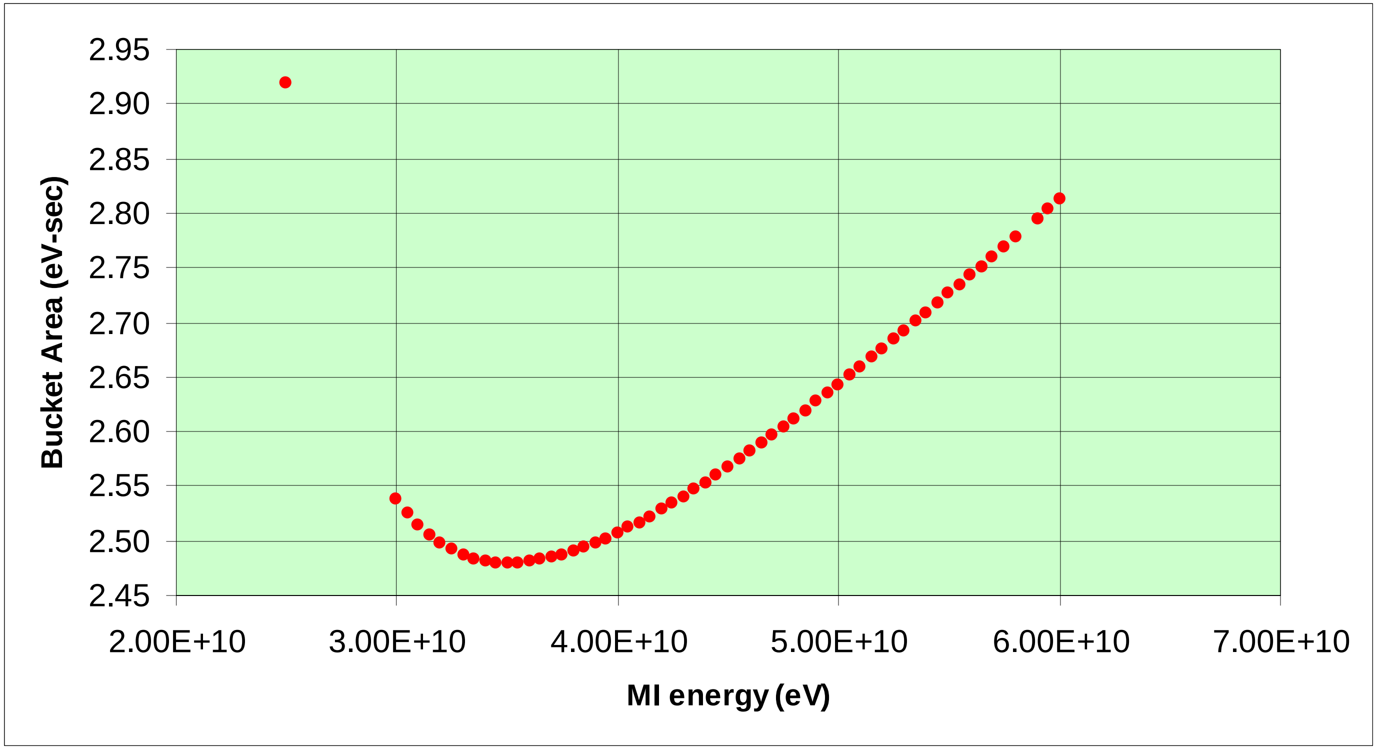
Accelerated Beam vs Acceleration Rate



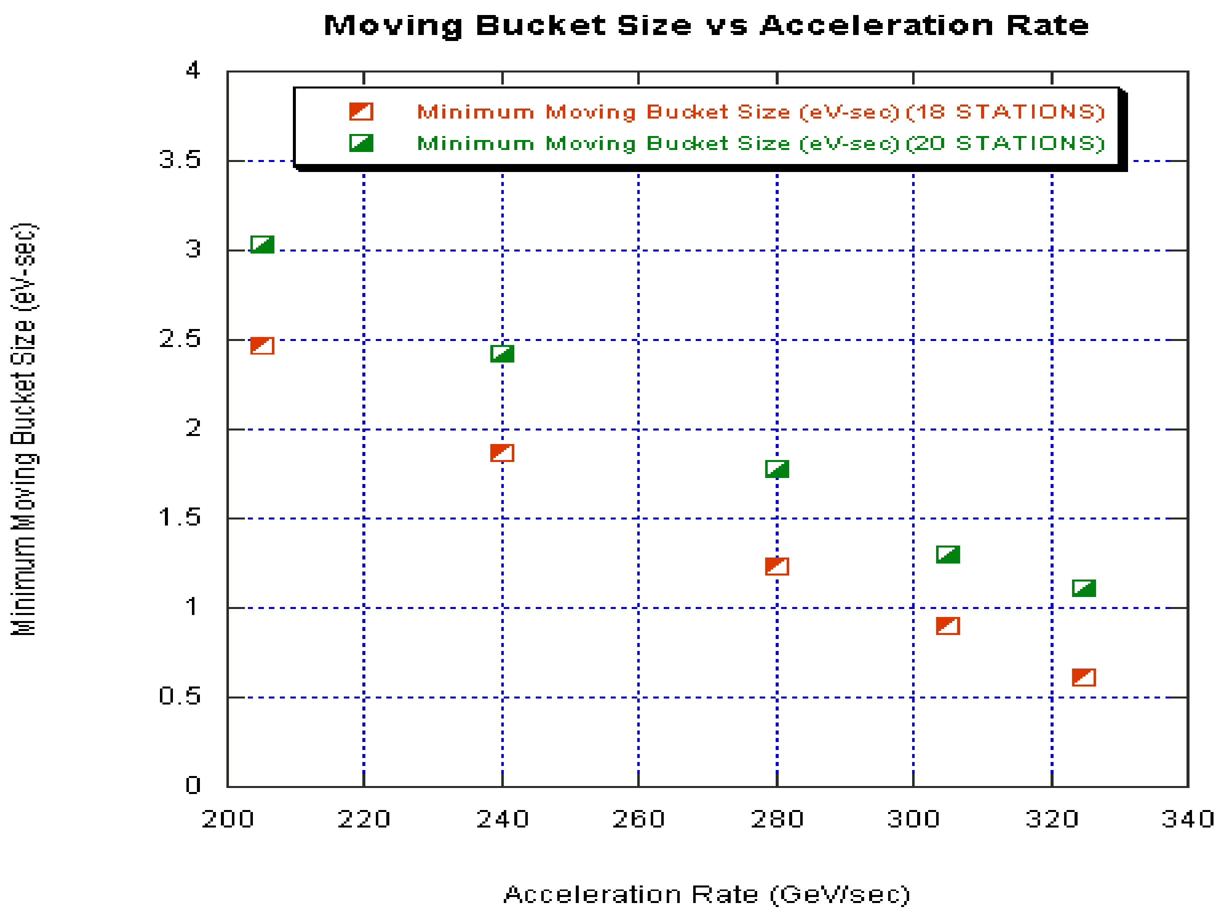
Bucket Area

- The moving bucket area available after transition depends on the acceleration rate and the RF voltage available not on the RF power.
- For a fixed RF voltage and acceleration rate the bucket area has a minimum at √3 times the transition Energy.
- We have found that in MI we need a moving bucket area larger than 1.8 eV-sec after transition with slip stacked beam.
- With 18 RF stations we cannot produce large enough bucket area in order to reliably accelerate slip stacked beam faster than 240 GeV/sec.

Moving Bucket Area vs MI energy for 4.32 MV (240 KV per Cavity) and 205 GeV/sec



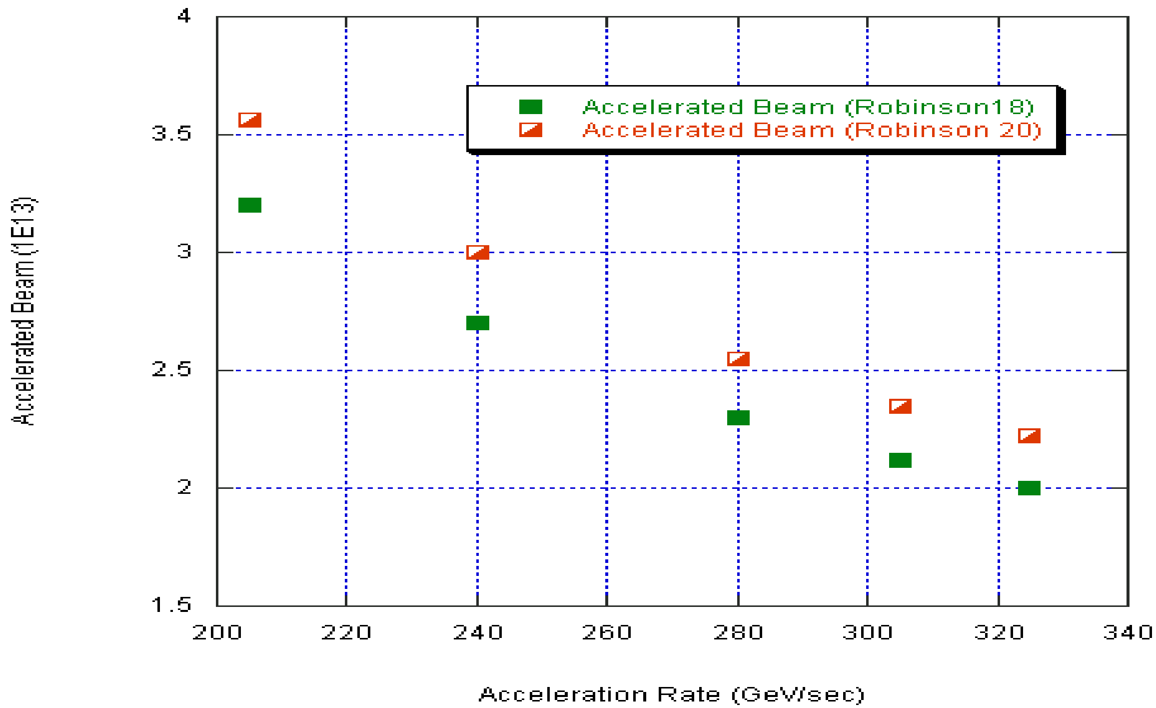
Moving Bucket Size vs Acceleration Rate



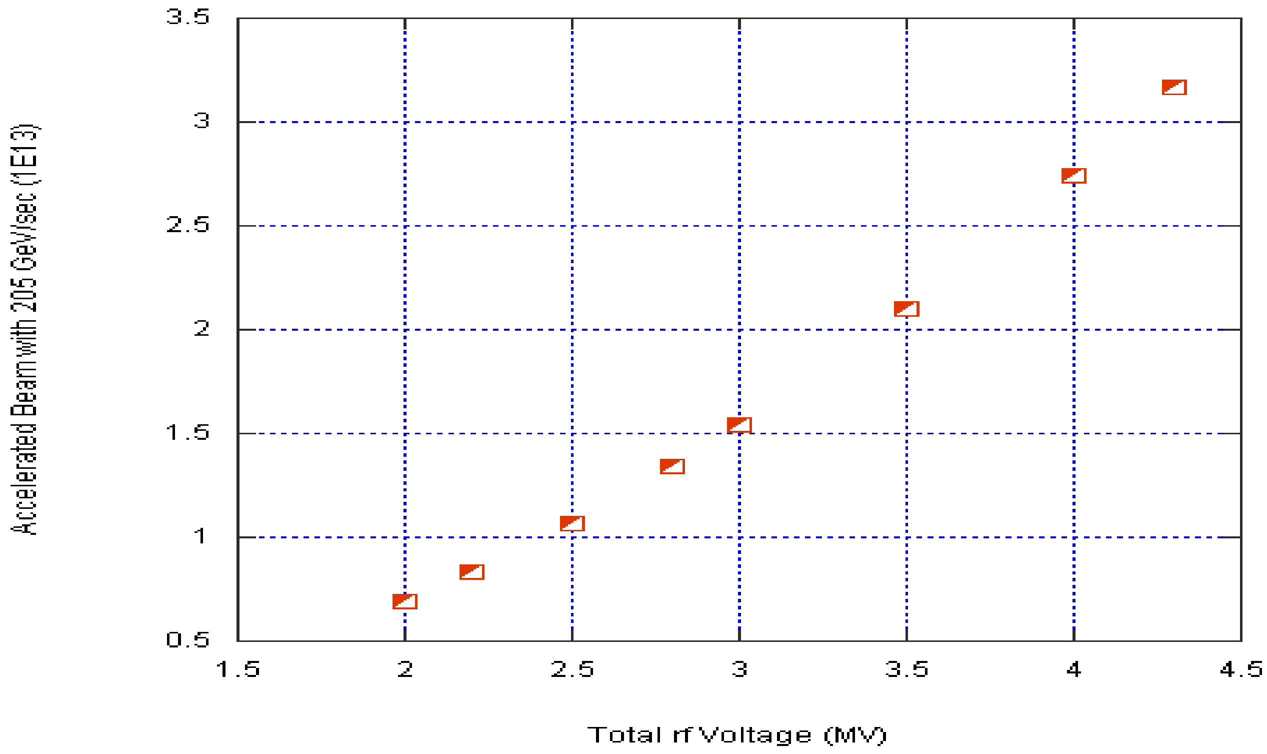
Stability Issues

- In the limit of Robinson Stability (with no beam loading compensation) the power we are dissipating in the Cavity should be greater or equal to the power we provide to the beam.
- The max amount of beam we can stably accelerate is a function of the max voltage and the shunt impedance.
- In MI we are using RF feed-back with typical gain of 6-10 effectively de-Qing each cavity by the same amount(R/Q remains the same) and increasing the instability threshold.
- In order to check the Robinson stability limits we decrease the rf voltage in a high intensity cycle till we see beam loss.

Allowable Accelerated Beam vs Acceleration Rate



Allowable accelerated beam at 205 GeV/sec vs voltage



Results

- In an $23 MI cycle we were able to accelerate up to 2.46E13 protons with 205 GeV/sec and rf voltage as low as 2.8MV thus exceeding the Robinson Stability limit by a factor of 1.84.
- From this result we conclude that the max amount of beam we can stably accelerate with the current rf system and 205 GeV/sec is 5.9E13protons (assuming we have the rf current and we are not going to exceed the power dissipation of the power tube).
- The reason that we could not raise the beam intensity higher was the Booster available Intensity.
- We could not lower the rf voltage much lower than 2.8MV due to the moving bucket area getting too small to contain the beam.

MI Beam accelerated with 205 GeV/sec

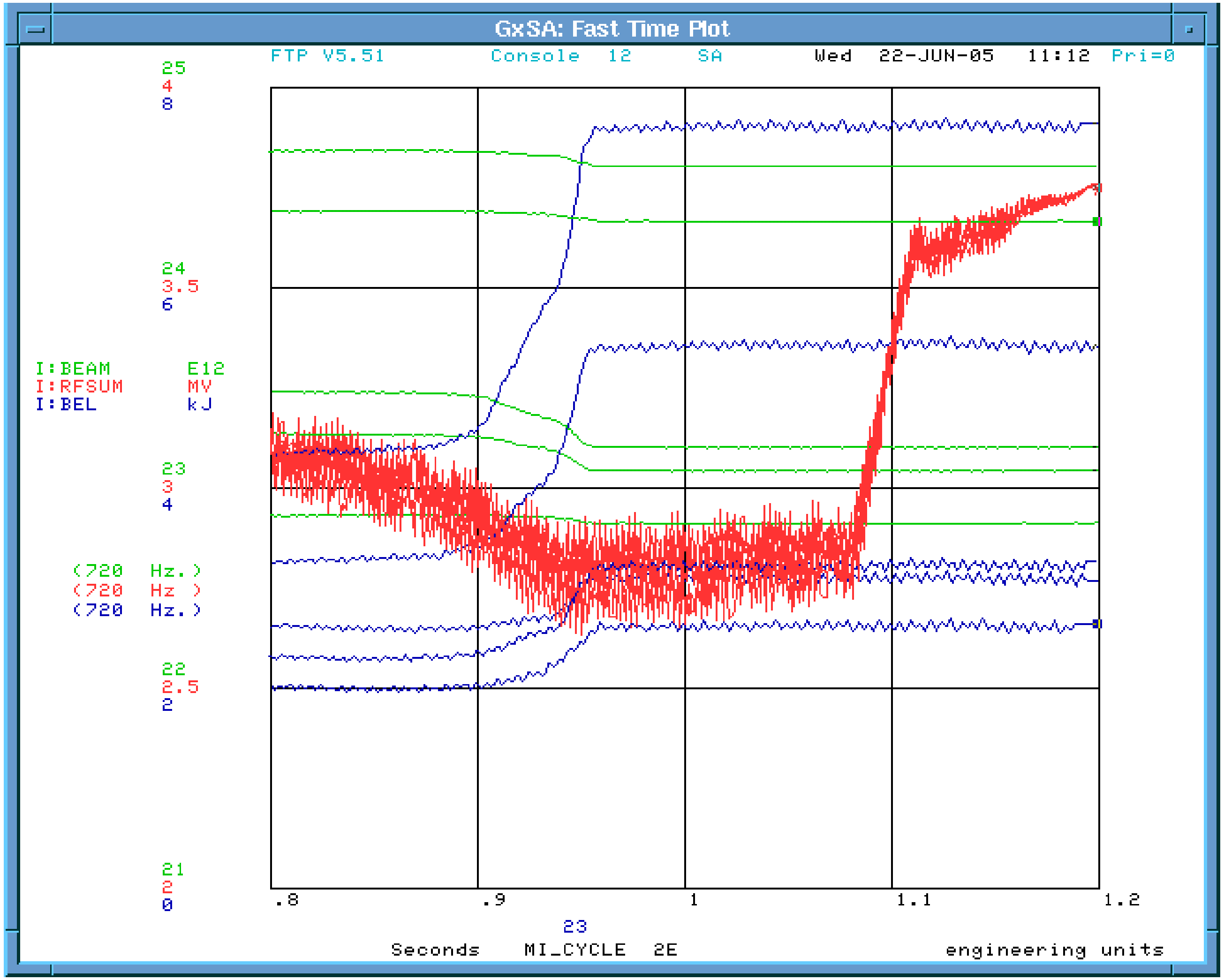


Plate and series tube Dissipation

- With our current RF parameters we have measured the total RF power, the PA plate dissipation and the modulator dissipation for 2.5E13p and they agree with the calculations to within 6%.
- The present modulator series tube dissipation is a concern during low voltage high current anode. Slip stacking is expected to exceed the anode dissipation limit at intensities above 5E13p.
  - Reduce the cavity RF voltage while leaving sufficient anode voltage on the PA, effectively reducing voltage drop across series tube.
  - Upgrade stations with new higher power modulators.
- The plate dissipation of the cavity PA appears to be fine up to 6E13p.

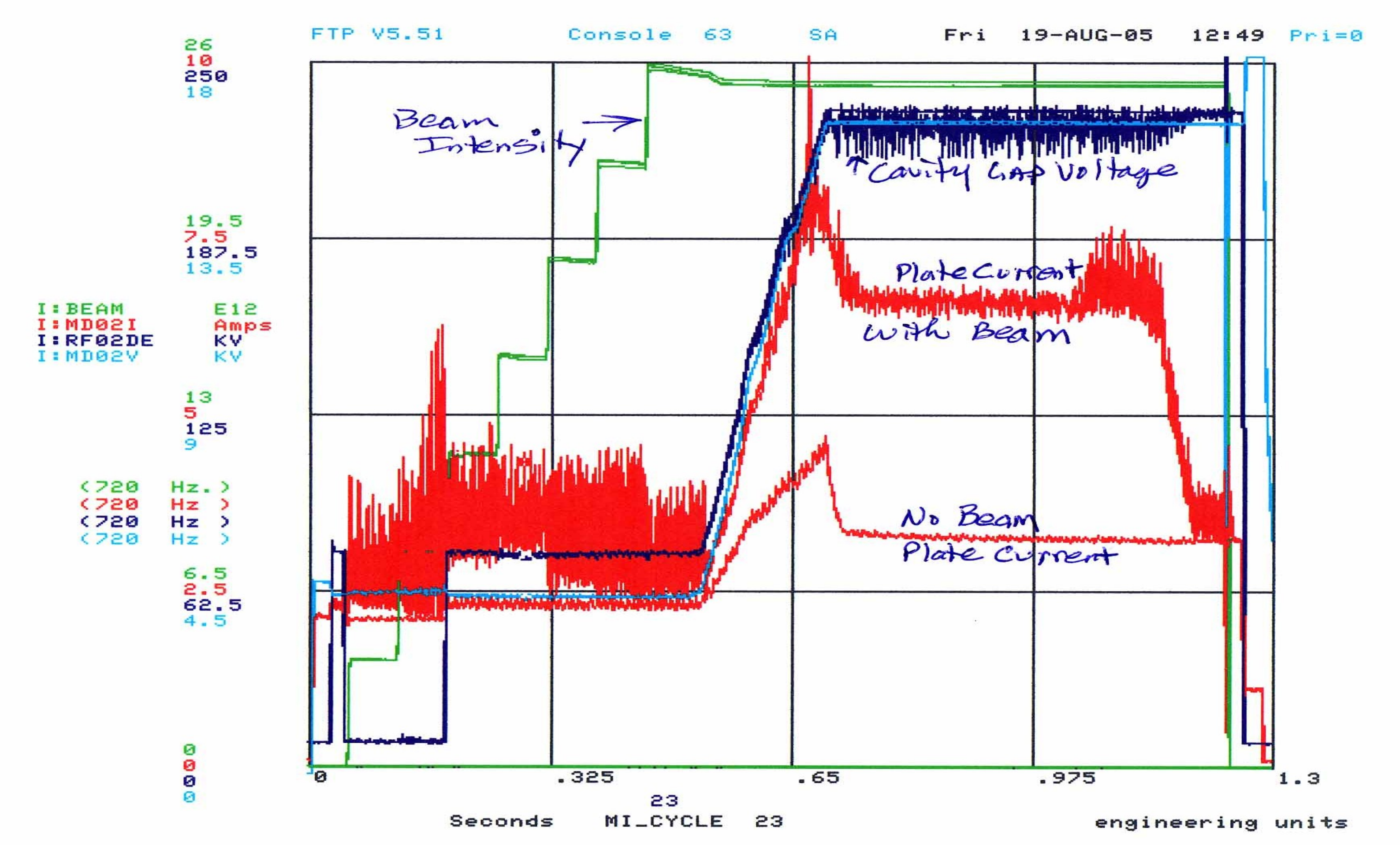
Power PA and Modulator Tube Dissipation

			PA	PA	PA	Anode Supply	Modulator	Modulator
Beam Intensity		Time	I plate	V plate	P in	Output voltage	I plate	Dissipation
		Sec	Amps	Kvolts	Kw atts	Kvolts	Amps	Kw atts
2.6 x 10^{13} protons	Injection	0.5	4	3.5	14	25	4	86
	Transition	0.1	8.5	17.5	148.75	25	8.5	63.75
	Flat top	0.6	6.5	17.5	113.75	25	6.5	48.75
5.2 x 10^{13} protons	Injection	0.5	7.5	3.5	26.25	25	7.5	161.25
	Transition	0.1	12	17.5	210	25	12	90
	Flat top	0.6	10	17.5	175	25	10	75

Measured

Calculated

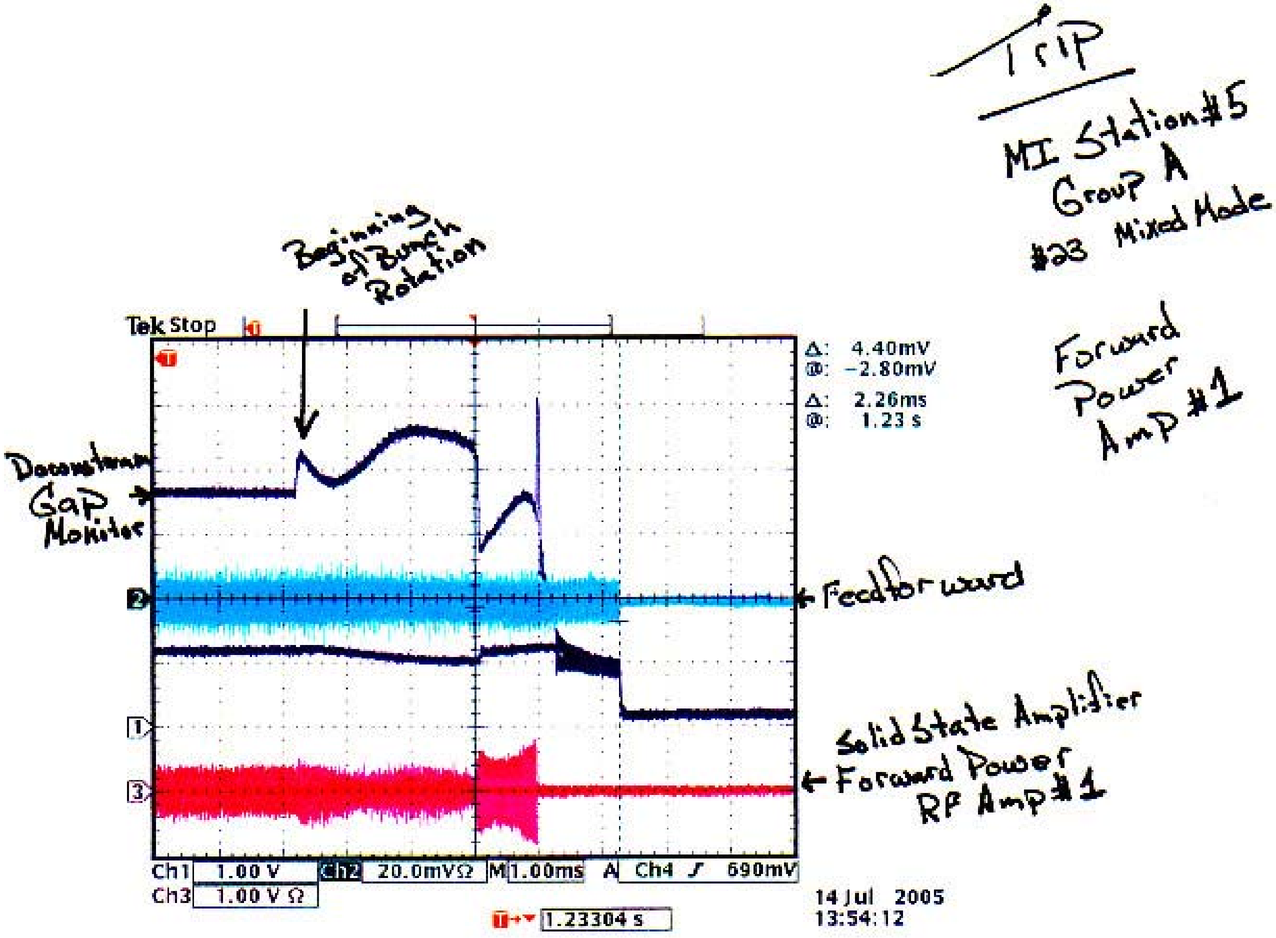
Gap Voltage and Plate Current for MIRF2



Other Issues

- The peak RF currents required during beam manipulations are of a concern.
- During transition crossing the RF phase has to be changed very fast while the beam loading is high.
- At 120 GeV we are performing a fast rotation in order to reduce the bunch length at the pbar target. Since the pbar beam gets extracted first in the mixed mode cycles the whole beam has to be rotated.

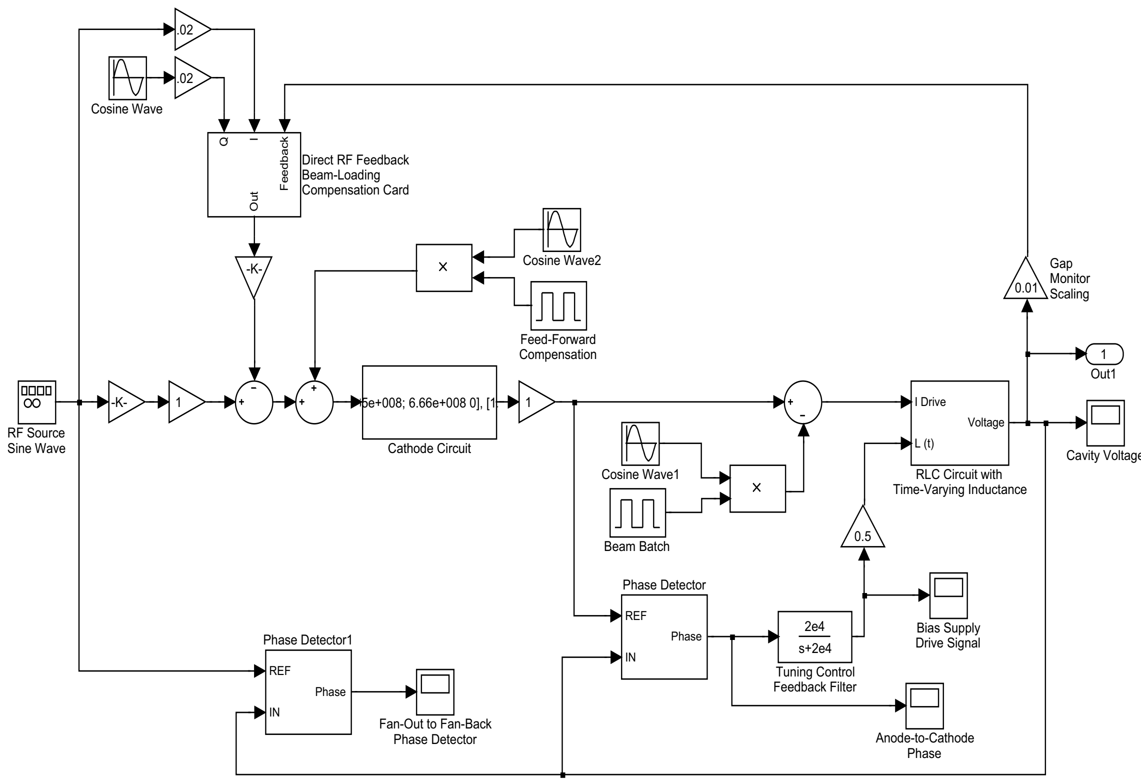
RF trip during Bunch Rotation



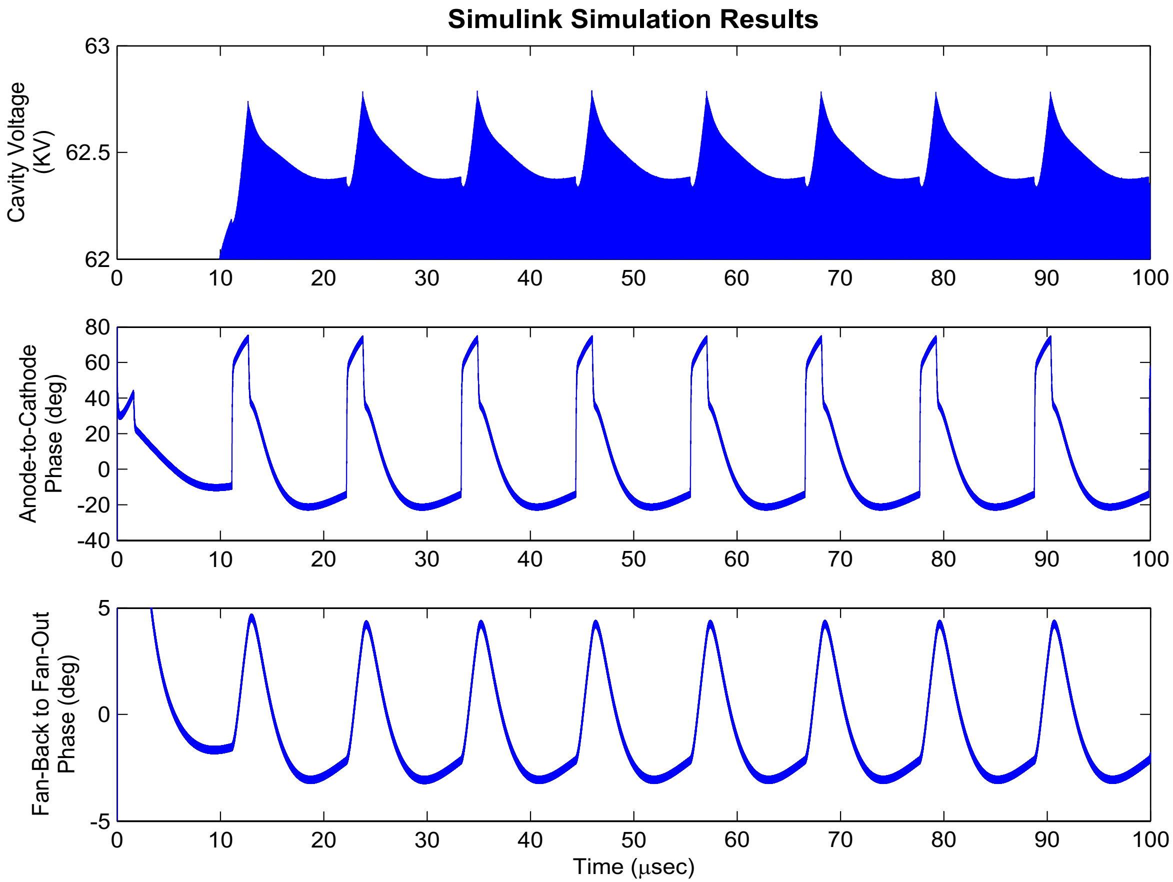
MI rf System modeling

- We have developed a generic tube performance simulator which calculates the instantaneous tube currents for an arbitrary bias point and load line.
- A more advanced version of the tube simulator using a phenomenological function fit is used to study the complex non-linear behavior of the 4CW150000E tube during dynamic simulations.
- We also have a Matlab Simulink model which models the dynamic behavior of a single MI RF system with its control loops and beam-loading compensation loops.
- All these model tools are expected to be used to help us understand the RF system demands but not beam stability.

Matlab Simulink model of a single RF system



Simulink Simulation Results



Conclusions

- We have enough power in the Current MI system to stably accelerate (to first order) up to 6E13 particles with 205 GeV/sec.
- Beam studies and simulations are needed to understand the peak RF current requirements and how to deal with fast phase jumps.
- The effect of coupled bunch modes on the beam stability needs to be studied.